Developing PyCam: Software for acquiring and processing volcanic UV SO_2 camera data

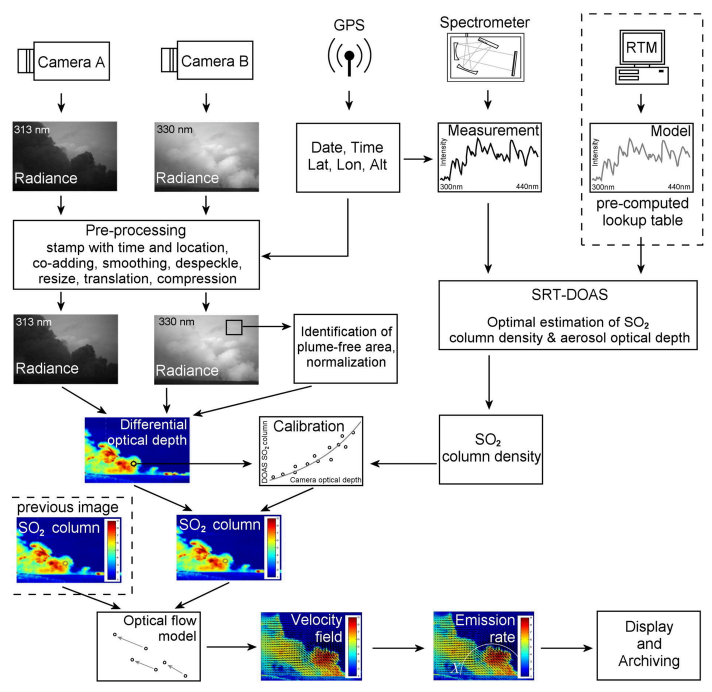
Daniel Brady, Thomas Wilkes, Tom Pering

University of Sheffield

Background

Gas emissions are one of the key ways in which volcanologists are able to determine the state of a particular volcanic system, and potentially provide a means of hazard forecasting (Sparks, 2003). Of the gases emitted, Sulphur Dioxide (SO_2) is one of the easier species to detect with remote sensing instruments; primarily due to its relatively low atmospheric concentrations and strong distinctive absorption bands at ultraviolet (UV) and infrared (IR) wavelengths.

One approach for measuring SO_2 emissions is through the use of ground-based UV sensitive cameras, achieved by equipping cameras with band-pass filters to capture images in 310 nm and 330 nm UV bands, corresponding to wavelengths with high and low SO_2 absorption, respectively. Taken together, these images are able to provide a measure of the optical depth for a volcanic plume, which can then be calibrated with data from an on-board spectrometer to provide estimates of SO_2 concentration within the plume.

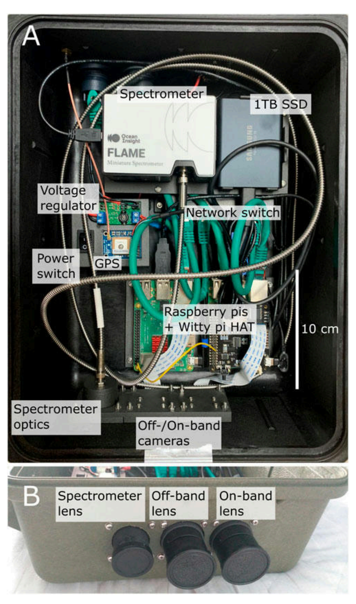


Schematic from Kern et al. (2015) showing the processing pipeline for estimating SO_2 emission rates using a UV camera

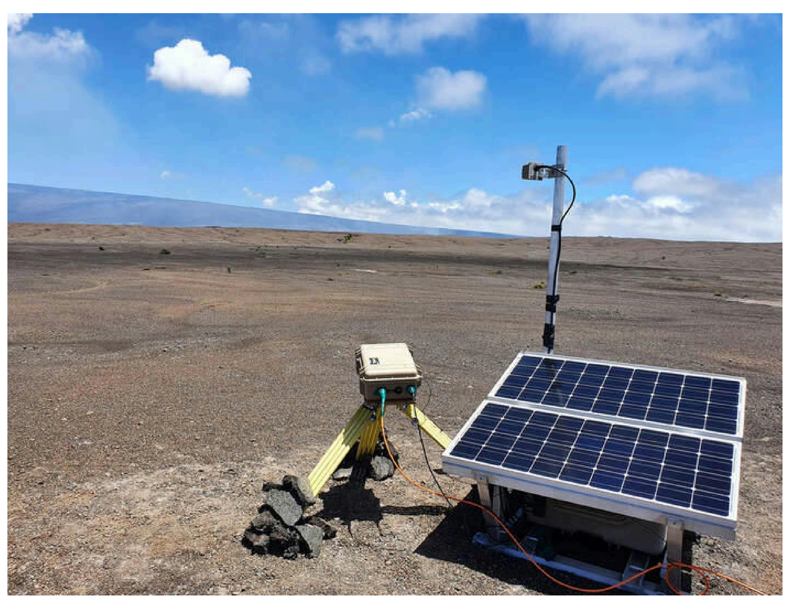
PiCam Hardware

While UV SO_2 cameras provide a high degree of temporal and spatial resolution for measuring volcanic emissions, their usage has been limited. This is partly due to the cost of the instrumentation, which until recently has relied on scientific-grade UV camera typically costing >10000 USD each.

The PiCam system developed by Wilkes *et al.* (2017) addresses the restrictive cost of such systems through the use of modified Raspberry Pi Camera modules. Removal of its Bayer filter enhances UV sensitivity of a Raspberry Pi camera module to create a low-cost UV camera alternative, aiding proliferation of such equipment to hazardous volcanoes around the globe.



PiCam Internals (from Wilkes et al. (2023))



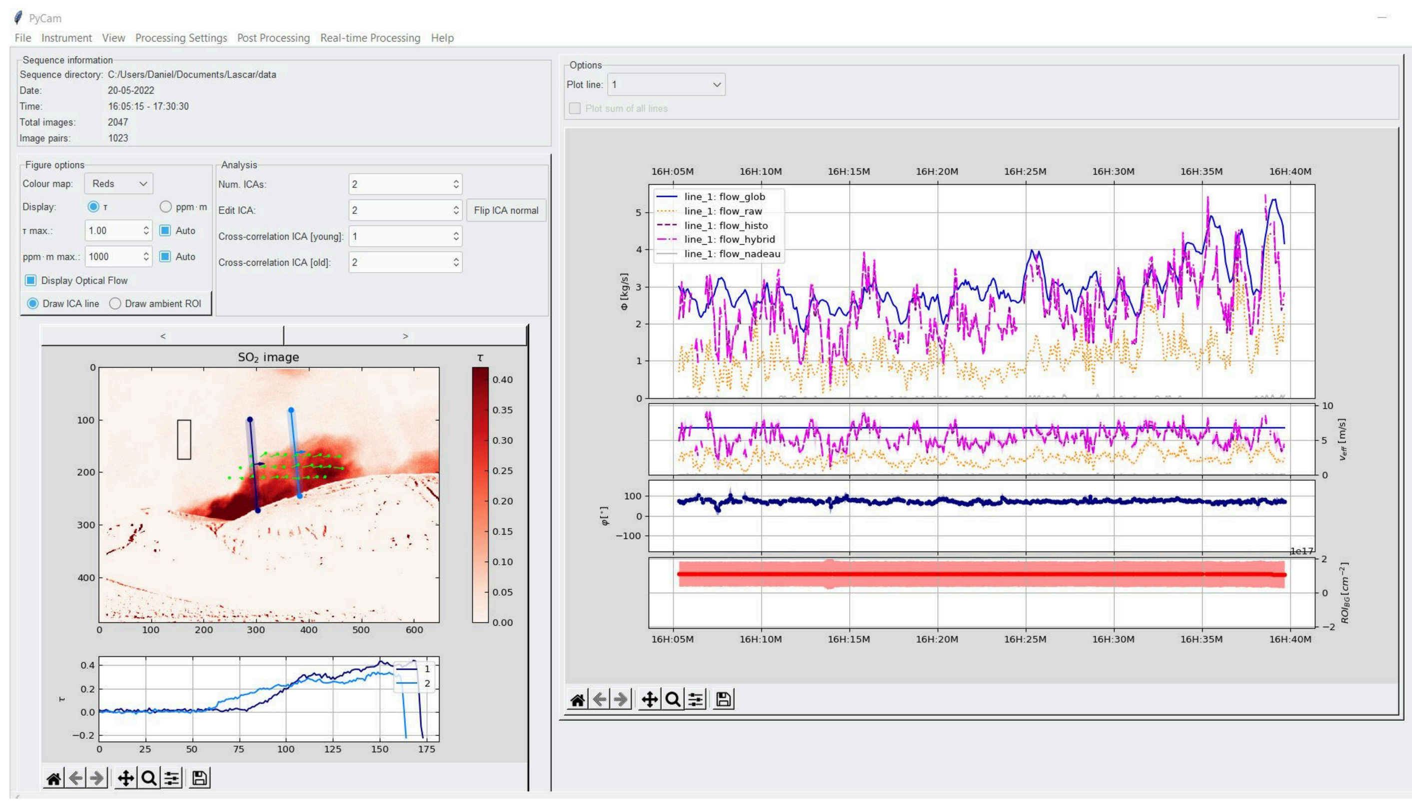
Permanent PiCam deployed at Kīlauea

To date, 6 PiCam systems are installed on active volcanoes around the world (Lascar, Chile; Lastarria, Chile; Cotopaxi, Ecuador; Reventador, Ecuador; Kīlauea, Hawaii; Merapi, Indonesia).

Locations of current or planned permanent deployments of PiCam

PyCam Software

PyCam began development in 2019 as a free and open source software package to complement the PiCam hardware. It is built using Python 3 and provides a Tk-based GUI interface as a user-friendly means of setting up data acquisition and processing the data captured.



Screenshot of PyCam processing data collected from Lascar, Chile

The data acquisition functionality of the software allows for manual acquisition during setup of the instrument, scheduling of data acquisition, and configuration of automated data acquisition.

The software allows both on- and off-line processing of the spectra and images captured. In order to process this data, PyCam provides an interface for established volcanic gas libraries, including pyplis (Gliß *et al.*, 2017), ifit (Esse *et al.*, 2020), and light dilution correction (Varnam *et al.*, 2020). It also incorporates other methods for estimating emission rates (e.g. The plume speed alogrithm from Nadeau, Palma and Waite (2011))

RSE Contributions

I began working on PyCam in Feb 2023, and have worked on it for approximately 16 months over two stints. My overarching goal has been to enchance the reproducibility, stability and usability of the software.

Direct contributions:

- Improved installation procedure and documentation
- Added configuration files that specify settings for a processing run
- Ensured that meta-data (e.g. configuration files) from a run are saved alongside the outputs
- Saving more of the data produced as part of processing (e.g. the calibration data).
- Added ancillary code to make testing features easier (e.g. script for mocking data transfer, container simulating FTP on a Raspberry Pi).

Indirect contributions:

- Better version control practices (use of branches and pull requests)
- Use of issues to record and communicate features/problems
- Use of releases and release notes to describe changes to the code

Roadmap

Software goals:

- Improve logging
- Disentangle the front- and back-end of the software, with the aim of GUI-less deployment
- Developing the testing suite and setting up continuous integration

Project goals:

- Next generation of PiCam (using Raspberry Pi 5)
- Develop data acquisition and processing pipeline

Conclusions

Overall, the impact of having an RSE on the project has been to allow the other team members to focus on scientific goals, knowing that the software side is in competent hands. It has also meant that development of the software has been accelerated, making something that is stable and usable for global collaborators.

Most notably, the code development has allowed near-real-time data to be displayed (since July 2024) in the monitoring observatory of Mount Merapi (BPPTKG headquarters), one of the most hazardous volcanoes in the world. Such work could therefore greatly impact hazard assessment at volcanoes where the PiCam instrument is installed.

PyCam Github Repo: github.com/twVolc/PyCamPermanent

Poster Github Repo: github.com/ubdbra001/RSECon24_Poster

Esse, B. *et al.* (2020) "iFit: A simple method for measuring volcanic SO_2 without a measured Fraunhofer reference spectrum," *Journal of Volcanology and Geothermal Research*, 402, p. 107000–107001. Available at: https://doi.org/10.1016/j.jvolgeores.2020.107000

Gliß, J. *et al.* (2017) "Pyplis–A Python Software Toolbox for the Analysis of SO_2 Camera Images for Emission Rate Retrievals from Point Sources," *Geosciences*, 7(4). Available at: https://doi.org/10.3390/geosciences7040134

Kern, C. *et al.* (2015) "An automated SO_2 camera system for continuous, real-time monitoring of gas emissions from Kīlauea Volcano's summit Overlook Crater," *Journal of Volcanology and Geothermal Research*, 300, pp. 81–94. Available at: https://doi.org/10.1016/j.jvolgeores.2014.12.004

Nadeau, P. A., Palma, J. L. and Waite, G. P. (2011) "Linking volcanic tremor, degassing, and eruption dynamics via SO_2 imaging," *Geophysical Research Letters*, 38(1), p. . Available at: https://doi.org/10.1029/2010GL045820

Sparks, R. (2003) "Forecasting volcanic eruptions," *Earth and Planetary Science Letters*, 210(1), pp. 1–15. Available at: https://doi.org/10.1016/S0012-821X(03)00124-9

Varnam, M. *et al.* (2020) "Quantifying Light Dilution in Ultraviolet Spectroscopic Measurements of Volcanic SO_2 Using Dual-Band Modeling," *Frontiers in Earth Science*, 8. Available at: https://doi.org/10.3389/feart.2020.528753

Wilkes, T. C. *et al.* (2023) "A new permanent, low-cost, low-power SO_2 camera for continuous measurement of volcanic emissions," *Frontiers in Earth Science*, 11. Available at: https://doi.org/10.3389/feart.2023.1088992

Wilkes, T. C. *et al.* (2017) "A Low-Cost Smartphone Sensor-Based UV Camera for Volcanic SO_2 Emission Measurements," *Remote Sensing*, 9(1). Available at: https://doi.org/10.3390/rs9010027